Public goods games on networks and in tumors

Valorization

"We must know. We will know."

David Hilbert

This addendum discusses the value-creation opportunities of the research presented in this dissertation. According to the Regulation Governing the Attainment of Doctoral Degrees of Maastricht University, examples of value-creation include "patents, licences, open source tools, software, making models and systems available, co-publications with social and/or economic stakeholders, publications in journals and newspapers, non-academic publications, appearances in the media, contributions to public debates, advice for social organisations or companies, projects for the SME portal, policy recommendations for governments, training programmes for professionals, public-sector workers, organisations or companies, participation in Top Institutes, in United Brains Limburg, collaborations in BioPartner, the Chemelot Campus, the Maastricht Health Campus, Campus Greenport Venlo, the Smart Services Campus, spin-offs and start-up companies, special collections, putting together exhibitions and/or catalogues, participation in administrative bodies."

Of the twenty-one items listed (counting the collaborations with the various local institutes as one), one is directly applicable to the body of work presented: publications in journals and newspapers. The paper based upon Chapter 5 was published in the Journal of Theoretical Biology in 2018, while the paper based upon Chapter 2 is, at the moment of writing, in submission. The papers based upon Chapters 3 and 4 are planned for submission in early 2019.

Given the theoretical nature of the research in this dissertation, other opportunities of value-creation – in the sense that the term was used in the regulations – are indirect and speculative. The remainder of this addendum hypothesizes on the value of each chapter, possibly falling in the contributions to public debates, advice for social organizations or companies, and policy recommendations for governments categories.

Fulfilling some other categories, such as software, making models and systems available, co-publications with social and/or economics stakeholders, non-academic publications, and appearances in the media, might follow from this body of research, but are impossible to speculate.

Chapter 2 considers the properties of the Nash equilibrium in network games. The relevance and value of the Nash equilibrium is, as I was led to believe, beyond dispute. With applications in many distinct fields of science, such as economics, computer science, and biology, the same seems true for networks. The chapter's main result states that, in a setting featuring sequential updates, if each player's update takes him closer to his current best choice, then for any initial condition and for any weighted network the play of the game approaches equilibrium. This result ties in, somewhat indirectly, with one of the most important central policy questions in economics, whether markets should be nationalized, regulated, or left alone. The first step in answering this question for a given market is figuring out the implications of a laissez-faire approach. This chapter's result states that weighted network games do not require regulations to reach an equilibrium state.

The core issue in **Chapter 3** is the value of foresight in network games. The level of the agents' foresight is a central characteristic of the agents of financial and economic models. The existence and convergence results of the chapter guarantee that the value of foresight can be calculated for any simple graph. Additionally, the convergence results ensure that the main results of Chapter 2 remain true in case of a single farsighted player whenever the network is characterized by a simple graph. Finally, the chapter's results allow for a qualitative description of the change in the value that the farsighted player receives upon the addition or the removal of a link. Part of the final result, the fact that the farsighted player is better off if two of his neighbors sever contact, is reminiscent of a type of jealousy, implying an indirect but nonetheless interesting connection between network games and psychology.

The topic of **Chapter 4** is very similar to that of Chapter 2. It focuses on the effect of introducing non-reciprocal relationships into the game, represented by a more general class of graphs, called directed networks. The chapter's main result identifies two classes of networks in which best-response cycles cannot exist, and hence, with some permissive assumptions, the convergence results of Chapter 2 remain true in these two classes as well. This result also extends the implications made on the laissez-faire approach in Chapter 2 to situations where the players' relationship is hierarchical, or when the own effects of the players are larger than their external effects. It is noteworthy, however, that convergence is not generally established for the whole class

of directed networks, hence the results, and therefore the implications, of Chapter 2 may not be robust for non-reciprocal relationships.

Chapter 5 is written with a specific application, cancer therapy, in mind. While it remains a theoretical work, the potential for value-creation is more direct and less general. The chapter's main result is that immunotherapy of cancer may worsen the patient's prognosis if it causes the tumor to switch from a selfish immune evasion strategy – such as hiding from the killer T-cells – to a cooperative one – such as immunosuppression. It is left for future research to assess the practical extent of this result and address it in a change in therapy as necessary. The model itself is part of a growing strand of literature aiming to understand cancer by the tools and paradigms of game theory, adding to the value of both research fields.

I conclude this addendum by a reflection on the value-creation process of science. Given the many global problems that humanity will need to solve for a sustainable, prosperous, and healthy existence, I fully sympathize with the goal of making science useful. There are two issues to note, however. The first is that no discovery exists in a vacuum; the value of individual pieces of research may not be immediately visible, may be uncertain at the time of their writing, or may come in a way that no one, including the researcher, expects. By having researchers focus on creating value in the short run, society deprives itself from broader discoveries and a deeper understanding, maybe even from value, in the long run. The second is that, as David Hilbert's quote also seems to suggest, human curiosity is tricky; the drive for discovery is often separate from the drive to create value. I find it therefore a non-trivial question whether any focus on value-creation is needed, be it in the short- or the long-run, in order to maximize the societal value of research.

I do not make these points to criticize any particular standing policy. However, I do find it troublesome when researchers self-select on the basis of the perceived usefulness or uselessness of their fields because it interferes with the communication between disciplines. If I am advocating for anything, it is for theorists to try to be interested in some of the more practical questions. Their more abstract thinking may make a connection that an applied person is too focused to make. On the other hand, I wish to reiterate the concerns that a friend of mine had against, as he/she called it, the "marginalization of fundamental research". Even if the amount of theoretical knowledge that will ever prove itself useful for humans is finite, I am quite positive we have not reached it yet. We should keep going.